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(54) **TRAITEMENT AU LASER DE LA TELANGIECTASIE**
(54) **LASER TREATMENT OF TELANGIECTASIA**

(57) L'invention concerne une méthode d'utilisation du laser pour coaguler des vaisseaux sanguins et, en particulier, de longueurs d'ondes entre 580 et 1 100 nm produites par une technique d'application d'impulsions multiples. La fluence nécessaire pour la photocoagulation et des dommages irréversibles aux vaisseaux est obtenue dans une séquence d'impulsions qui permet le chauffage cumulatif du vaisseau irradié. Chaque impulsion utilise une fluence infraliminaire obtenue à un taux de répétition calculé basé sur le temps de relaxation thermique des vaisseaux visés afin de permettre un chauffage efficace. Le fait d'utiliser plusieurs impulsions à une fluence inférieure à ce qu'il serait nécessaire si l'énergie était livrée dans une impulsion permet d'éviter l'onde de choc thermique qui entraîne la rupture des vaisseaux et une hyperpigmentation non souhaitée. Des fluences inférieures réduisent également le risque de blessures épidermiques et de cicatrices indésirables. Cette méthode est particulièrement utile pour traiter la télangiectasie dans les jambes.

(57) The present invention is a method of using a laser to coagulate blood vessels and, in particular, using wavelengths between 580-1100 nm delivered in a multiple pulse technique. The fluence required for photocoagulation and irreversible vessel injury is delivered in a sequence of pulses which allows for cumulative heating of the irradiated vessel. Each pulse utilizes a subthreshold fluence delivered at a calculated repetition rate based on the thermal relaxation time of the targeted vessels to allow for efficient heating. Using several pulses at a lower fluence than would be required if the energy were delivered in one pulse avoids the thermal shock wave which results in vessel rupture and unwanted hyperpigmentation. Lower fluences also reduce the risk of epidermal injury and unwanted scarring. This method is particularly useful in the treatment of leg telangiectasia.

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LASER TREATMENT OF TELANGIECTASIA

FIELD OF THE INVENTION

This invention relates to a laser treatment for coagulating blood vessels and, in particular, to a laser treatment for leg telangiectasia.

BACKGROUND OF THE INVENTION

Telangiectasia derives from Latin roots meaning "dilated end vessel". In clinical medicine, the term is used to describe superficial cutaneous vessels which become visible to the human eye. These vessels measure 0.1 millimetre (100 microns) to 1-3 millimetres in diameter. The dilated vessel may involve a venule capillary or arteriole. Telangiectasia arising from capillaries are initially of fine calibre and red in colour, but may become larger and blue or purple in colour because of increasing backflow from the venous side. Those arising from venules are larger in calibre and blue in colour. They often protrude and appear tortuous.

Facial telangiectasia respond well to laser treatment which is now generally accepted as the standard of care. Laser energy is targeted to the main chromophore in blood which is oxyhemoglobin. Present technology utilizes yellow light in the 577-585 nm wavelength to treat these small vessels primarily of capillary origin. These shorter wavelengths have limited penetration and are well absorbed by oxygenated haemoglobin in capillaries and arterioles but not by deoxyhaemoglobin in venules. Therefore, this technology is less effective against deeper, larger vessels and particularly venous telangiectasia commonly seen in the lower limbs.

Disfiguring or symptomatic telangiectasia of the leg can occur in 29-40% of women and 5-15% of men. Although some patients may have painful symptoms, most patients seek treatment for cosmetic reasons. Any effective form of

treatment should therefore be relatively free from complications, particularly pigmentary changes or scarring.

The general standard of care for leg telangiectasia is sclerotherapy. Various studies suggest that the rate of clearing is 60-70% but up to 30% of patients can develop post-treatment pigmentation and/or telangiectatic matting. The hyperpigmentation is caused by the extravasation of red blood cells after vessel injury.

The pulsed dye laser was developed to treat benign vascular lesions. Numerous studies have shown it to be effective in the treatment of small microvessels in the 50-300 micron range (up to 0.3 millimetre) such as occurs in port wine stains, facial telangiectasia and fine leg telangiectasia. A basic assumption is that a temperature increase of 50° C is generally required to coagulate these vessels. It is well documented that a flashlamp pulsed dye laser at 585 nm and 450 microsecond pulse width effectively coagulates microvessels up to 0.3 millimetre without adverse effects on the surrounding skin. However, the flashlamp pulsed dye laser does not produce enough heating and penetration for effective coagulation of vessels larger than 0.3 millimetre. The average diameter of blood vessels in the deeper dermis is 0.4 millimetre and near subcutaneous tissue vessels may be as large as 1-3 millimetres in diameter.

Various lasers have been used to treat leg telangiectasia with limited success. Unwanted side effects, such as hyperpigmentation still occur at significant rates. Laser treatment using a wavelength of 577-585 nm in submillisecond pulses produces a photoacoustic shockwave or thermal shock which results in extravascular purpura leading to post-treatment hyperpigmentation. Therefore, current research is directed towards utilizing longer wavelengths delivered in longer pulses to achieve more gentle heating to avoid the thermal shock of shorter pulsed duration. A flashlamp pulsed dye laser is now available from the Candela Corporation with

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a longer pulse duration of 1.5 milliseconds. Other systems include a non-coherent pulsed light source developed by Energy Systems Corporation. Early reports indicate that conventional treatment of leg telangiectasia using these systems is still limited by hyperpigmentation and other unwanted side effects.

In *Selective Photothermolysis: Precise Microsurgery by Selective Absorption of Pulsed Radiation*, Science 1983:220:524-527, Anderson and Parrish proposed a scientific model for the ideal vascular laser and developed the theory of selective photothermolysis. They postulated that the use of yellow light in pulses between 300 microseconds to 5 milliseconds would prevent non-selective thermal injury. The most important criteria was that a wavelength which is absorbed preferentially by the target chromophore was delivered in a pulse whose duration did not exceed the thermal relaxation time (TRT) of the target chromophore. The TRT of a tissue is the time it takes to lose 50% of its heat after irradiation.

The theory of selective photothermolysis requires that the pulse duration be shorter than the thermal relaxation time. For superficial cutaneous vessels, the thermal relaxation time varies between 0.1 milliseconds to 10 milliseconds depending on the size and type of vessel. The average thermal relaxation time for vessels in typical vascular lesions is 1.2 milliseconds. The flashlamp pulsed dye laser used to treat port wine stains and other vascular lesions is pulsed at 0.45 milliseconds which is less than the average thermal relaxation time of 1.2 milliseconds. However, vessel size varies between arterioles which have thermal relaxation times of hundreds of microseconds to larger venules of adult port wine stains which have thermal relaxation times of up to tens of milliseconds. Therefore, even in the typical port wine stain, there are vessels with thermal relaxation times ranging over three orders of magnitude and it is

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simplistic to define a single thermal relaxation time for the target lesion.

In the treatment of leg telangiectasia where the target vessel is generally of a uniform size, it is possible to have a single thermal relaxation time for the target area. A longer pulse duration can be utilized as long as the thermal relaxation time is not exceeded. Pulsed durations longer than 1.5 milliseconds are not easily achieved using flashlamp pulsed dye technology. For larger vessels above 300 microns, longer pulse durations beyond five milliseconds would still meet the requirements for selective photothermolysis and allow the delivery of higher energies while reducing the thermal shock as the pulse duration increased. The results show that microhemorrhage related to thermal shock may be reduced with the longer pulse duration but it is not eliminated. However, technological limitations also make it unlikely that a longer pulse duration will be attainable with conventional laser systems.

There, therefore, remains a need for an effective method of using a laser for coagulating vessels in vascular lesions, telangiectasia and the like, having larger and/or deeper vessels. In particular, there is a need for an effective treatment for leg telangiectasia. As well, there is a need for an effective treatment which reduces or eliminates unwanted side effects such as hyperpigmentation and other unwanted side effects.

SUMMARY OF THE INVENTION

The present invention overcomes the disadvantages of prior assemblies and provides a method of using a laser to coagulate vessels in vascular lesions, telangiectasia and the like, having larger and deeper vessels and, in particular, leg telangiectasia. The present invention also reduces the occurrence of hyperpigmentation and microhemorrhaging.

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According to the present invention then, there is provided a method of using a laser to coagulate vessels comprising the steps of applying multiple pulses of a laser to a target vessel area, in appropriate energy and pulse duration and in which the pulse repetition rate is approximately equal to or less than the inverse of the thermal relaxation time of the target vessel to cause cumulative heating resulting in coagulation of the vessel without excessive heating of the surrounding tissue.

DETAILED DESCRIPTION

The present invention is a method of using a laser to coagulate blood vessels. It may be used in several clinical applications. For example, it may be used to treat telangiectasia, venous malformations, hemangiomas, striae, capillary malformations and, in particular, lesions resistant to conventional treatment using a submillisecond flashlamp pulsed dye laser. In particular, it is useful in the treatment of leg telangiectasia. It can be used effectively by dermatologists and other laser therapists involved in cutaneous medicine treating larger sized vessels. This method comprises applying multiple pulses of a laser to the blood vessels in a target area wherein the wavelength, pulse duration, energy, and repetition rate of the laser pulses are determined primarily according to the vessel size and depth.

One surprising aspect of the present invention is the effect of multiple pulses on larger vessels. Conventional treatments have been largely unsuccessful on larger vessels due in part to the inability to provide sufficient energy and heating to the vessel to produce coagulation without unwanted side effects like the scarring of the tissue. By applying multiple pulses of a laser at a lower energy, sufficient heating can be produced to coagulate larger vessels and yet largely avoid unwanted side effects such as scarring. To achieve efficient heating of the vessel from the multiple

pulses, the pulses must be delivered at a repetition rate which allows for a sequential increase in temperature from each pulse. The multiple pulses are applied at a repetition rate that is below the thermal relaxation time (TRT) of the vessels in the target area and at a wavelength which can penetrate to the depth of the vessel and be absorbed by the vessel. The preferred repetition rate of the pulses measured in units of Hertz is approximately equal to 1/TRT.

An essential concept of the treatment of the present invention is the matching of the pulse duration and repetition rate of the laser to the vessel diameter. Although vessel size and, therefore, the thermal relaxation times vary between arterioles and larger venules, target selectivity is possible in selective photothermolysis by selecting an appropriate pulse duration. In port wine stains, the larger ectatic vessels are the targets and it is their thermal relaxation time which should not be exceeded. Therefore, a pulse duration of up to five milliseconds would still be appropriate. When the pulse duration exceeds the thermal relaxation time of the target, heating becomes inefficient since the vessel is already cooling before heating is complete. It also provides the basis for non-selective scarring due to the conduction of heat to the surrounding tissue. Laser pulse duration and therefore the exposure time of the vessel less than the thermal relaxation time confine the heat to the target chromophore and increase selectivity. The 0.45 millisecond pulse duration of the flashlamp pulsed dye laser spares small capillaries in the 0.01 to 0.05 millimetre range since they have cooled significantly during the delivery of laser energy.

The multiple pulse protocol of the present invention is the best avenue for treating larger vessels. The present invention shows that multiple pulse techniques reduce the risk of microhemorrhage for any technology and can produce cumulative heating to attain the required change in

temperature for threshold coagulation of a target vessel. One step in the present invention is the calculation of the optimal laser pulse energy required for the target vessel. The optimal energy is determined by relating the vessel size and depth to the oxyhemoglobin absorption rate using industry standard calculations. The standard of comparison for the net energy required to coagulate a given vessel at a given depth is calculated using a clinical model of a 300 micron vessel at 0.5 millimetre depth treated by a flashlamp pulsed dye laser. Optimal treatment parameters may be selected from the following table:

TABLE 1

VESSEL SIZE/DEPTH	NM.	PULSE WIDTH-MSEC.	ENERGY J/CM2	SKIN TEMP. CHANGE	SKIN/VESSEL TEMP. RATIO
300 microns/0.5 mm.	585	0.45	8	12.33	0.24
	580-780	5	26	12.25	0.24
500 microns/0.5 mm.	585	0.45	13	19.0	0.38
	580-780	15	28	10.0	0.20
1 mm./0.5 mm.	585	0.45	24	48.5	0.97
	580-780	30	34	21	0.42
1 mm./1.0 mm.	780-1000	100	36	11	0.22

Ideally, treatment parameters that produce the lowest change in epidermal temperature with a low skin/vessel temperature ratio are preferable. From Table 1, skin/vessel temperature ratios of 0.24 or less suggest the preferred wavelengths. It is obvious from the table that a flashlamp pulsed dye laser at 585 nm with a pulse duration of 0.45 milliseconds cannot treat larger, deeper vessels. The energy required to coagulate these vessels produces too much epidermal heating as shown by the high ratios 0.38 and 0.97 for vessels 0.5-1.0 millimetre in diameter resulting in scarring and other side effects.

As previously stated, a flashlamp pulsed dye laser at 585 nm and 450 microseconds pulse width coagulates microvessels up to 0.3 millimetre in diameter without adverse effects on the surrounding skin. The required energy using this combination of wavelength and pulse duration is 6-8 joules/cm^2 for a vessel having a diameter of 0.3 millimetre at a depth of 0.5 millimetre. Using these treatment parameters, there is a change in skin temperature of 12.3°C and a skin/vessel ratio of 0.24. Theoretically, treatment parameters which achieve the lowest skin/vessel temperature ratio and effective coagulation are considered to be the most ideal. The limitation of a 585 nm x 450 microsecond pulsed dye laser is illustrated by analyzing the calculations for treatment parameters of a vessel measuring 0.5 millimetre at the same depth of 0.5 millimetre. In this situation, at 585 nm, the energy required to achieve threshold heating would be 12.6 joules/cm^2. However, the significant concern is that the elevation in skin temperature would be 19°C with the skin/vessel temperature ratio rising to 0.38. This means that a substantial increase in epidermal heating would occur which would likely result in clinical scarring. The higher peak powers resulting from using the higher fluence delivered in the same pulse duration also results in significant thermal shock and microhemorrhage. Using a longer pulse duration to deliver the required energy is the basis for the development of a flashlamp pulse dye laser with a longer pulse duration at 1.5 milliseconds. Increasing the wavelength increases the depth of penetration which makes longer wavelengths more useful for deeper vessels between 0.5 and 1.0 centimetre depth.

Another step in the method of the present invention is the selection of an appropriate wavelength and pulse duration. One feature of the present invention is the relationship between the wavelength and pulse duration which gives the required energy to increase the temperature of the target

vessel above the threshold for coagulation while maintaining the optimal skin to vessel temperature ratios. Utilizing a pulse duration shorter than the thermal relaxation time reduces the risk of scarring by minimizing the transfer of heat conducted to surrounding tissues. It also provides for more efficient heating since active heating occurs before the effects of passive cooling can be felt. A laser system which delivers the required wavelength and approximate pulse duration is therefore optimal.

The appropriate wavelength to be used in the treatment of a particular vessel is determined based upon a number of factors. These factors include, among others, the type of vessel, for example whether it is a capillary, artery or vein; degree of oxygenation; the size and depth of the vessel; the thickness of the vessel wall; and haemodynamic factors such as flow and viscosity. As an example, one important factor used to determine the wavelength is the absorption curves for deoxyhemoglobin for venous telangiectasia and oxyhemoglobin for arterial and capillary telangiectasia. The absorption peak at 585 nm for oxyhemoglobin indicates that wavelengths near this peak are more optimal for capillary or arterial telangiectasia. These vessels appear pinkish or more red. However, the 585 nm wavelength has limited penetration. Using longer wavelengths in the 590-615 nm range provides for adequate absorption and increased penetration to deeper capillary or arterial vessels. To treat venous telangiectasia, wavelengths in the range of 585 -1000 nm may be used although the longer wavelengths are preferred. For example, a relatively well oxygenated superficial capillary type telangiectasia of small calibre, for example less than 500 microns, will respond well to wavelengths in the 585-615 nm range. A suitable laser would be a long pulse (pulse duration of 1.5 milliseconds) flashlamp pulsed dye laser. For vessels in the deeper dermis of medium calibre (0.5-1.0 millimetre), a longer wavelength is preferable. If the vessel

is more venous in nature, then the longer wavelength is well absorbed by deoxyhemoglobin and is still well enough absorbed by oxyhemoglobin to treat capillary type telangiectasia. Wavelengths around 620-700 nm are useful and a long pulse Ruby laser (2-3 milliseconds) is suitable. For deeper vessels near subcutaneous tissue, an Alexandrite laser at 750 nm in a long pulse system (1-2 milliseconds) is appropriate.

A further step is to select the repetition rate best suited for the vessel diameter and thermal relaxation time to achieve efficient cumulative heating of the target vessel. The thermal relaxation time (TRT) of a vessel varies with a number of factors including diameter and shape. For any given thickness, spheres cool faster than cylinders which cool faster than planes. Vessels are cylindrical but the tissue layers are planar. Complicated formulas can be used to calculate the TRT but a simple rule of thumb provides a reliable approximation. The TRT in seconds is roughly equal to the square of the target dimension in millimetres. Therefore, for a vessel measuring 0.1 millimetre (100 microns), the TRT is approximately 10 milliseconds. For vessels up to 0.50 millimetre or 500 microns the TRT is up to 250 milliseconds or 0.25 seconds. Therefore, it is apparent that smaller vessels cool more quickly. To achieve efficient heating from multiple pulses, the pulses must be delivered at a repetition rate which allows for a sequential increase in temperature from each pulse. For small vessels, the repetition rate needs to be rapid. For example, a 300 micron vessel with a 90 millisecond TRT cannot be efficiently heated by multiple pulses using the present technology which only achieves repetition rates in the order of 1-2 Hz or 1-2 pulses every second. However, these small vessels do not require multiple pulses as they are effectively coagulated using a standard flashlamp pulsed dye laser. For larger vessels, repetition rates of 1-2 Hz can be effective in producing cumulative heating. For example, a vessel of 1.0 millimetre

diameter has a TRT of one second and a vessel of 0.5 millimetre has TRT of 0.25 seconds. At a repetition rate of 1 Hz, the smaller vessel would have lost most of its heat within the one second time frame. At 2 Hz, the smaller vessel would lose most of its heat but there would be some incremental increase in temperature after each pulse. The larger vessel would have lost 50% of its heat after one second and sequential pulses would be more effective in producing cumulative heating.

A number of experiments were conducted to confirm the concept of using multiple pulses to treat larger calibre vessels. The first objective was to investigate whether multiple pulses could achieve effective heating with a lower degree of thermal shock or vessel rupture.

TABLE 2		
wavelength (nm)	585	585
pulse duration (microseconds)	450	450
number of pulses	1	4
energy (joules/cm²)	6	4
repetition rate (Hz)	--	1

Five subjects with untreated port wine stains were studied. Adjacent areas measuring two square inches were outlined in each subject, labelled appropriately and photographed. Each subject was treated with a Candela Corporation flashlamp pulsed dye laser utilizing a wavelength of 585 nm, and a pulse duration of 450 microseconds. A standard single pulse technique using a fluence of 6.0 joules/cm^2 was used to treat one area and a multiple pulse technique using 4 joules/cm^2 delivered in four pulses at a repetition rate of 1 Hz was used to treat the adjacent area. At one hour and 24 hour intervals after treatment, each subject underwent skin biopsies. Each subject was seen at three months to assess the degree of fading. The skin biopsies were reviewed by an independent

dermatopathologist and assessed for a variety of histologic findings including the degree of subendothelial injury, edema in the perivascular cuff and the degree of microhemorrhage or extravasation.

The results confirmed that multiple pulses produced effective coagulation as there was no significant difference in the degree of fading between each treatment method. There was a significant difference in the degree of microhemorrhage seen at both one and 24 hours. There was little, if any, microhemorrhage at 24 hours in the multiple pulse sites as compared with florid microhemorrhage seen at the single pulse sites.

The study described above was repeated using a flashlamp pulsed dye laser with a pulse duration of 1.5 milliseconds with another five subjects with untreated port wine stains. Once again, there was no significant difference in the degree of fading obtained but microhemorrhage were less evident with multiple pulses and lower fluences as compared to a higher fluence delivered in a single pulse. A longer pulse duration decreased the degree of thermal shock but required the use of higher fluences.

A further clinical study was carried out in ten subjects with leg telangiectasia.

TABLE 3					
wavelength (nm)	590 and 595				
number of pulses	1	1	4	5	6
energy (joules/cm^2)	15	20	8	8	8
repetition rate (Hz)	--	--	.8	.8	.8

The study had two arms: one using a 590 nm wavelength and another using a 595 nm wavelength. At each wavelength, three sites were treated using a single pulse technique at fluences of 15 joules/cm^2 and 20 joules/cm^2. In the same patients, three adjacent sites were treated using a multiple pulse

technique of 8.0 joules/cm² at four, five, and six pulses delivered at a repetition rate of 0.8 Hz. Patients were seen at 3, 6 and 12 weeks after treatment. Rates of clearing and side effects were assessed. Each method of treatment achieved a 60% rate of fading. However, the degree of post-treatment hyperpigmentation was reduced from 80% in the single pulse sites to 10% in the multiple sites.

These experiments confirm that the energy required for irreversible vascular injury can be delivered in multiple sequential pulses at a critical repetition rate instead of a single pulse without any loss of efficacy. As well microhemorrhage which is an unwanted side effect of single pulses can be significantly reduced by using multiple pulses at appropriate parameters.

The following examples illustrate some of the preferred parameters for application of the present invention to target vessels in telangiectasia.

For the application of the present invention to vessels in the superficial dermis having a depth of up to approximately 0.5 millimetre, the following criteria may be used.

TABLE 4

vessel depth	0.5 mm.	
vessel size	300 microns	
wavelength (nm)	585 - 595	
pulse duration (milliseconds)	1.5	1.5
number of pulses	1	3-5
energy (joules/cm²)	15-20	8-12
repetition rate (Hz)	--	5-10

For vessels having an approximate diameter of 300 microns, wavelengths in the 585-595 nm range are preferred. A flashlamp pulsed dye laser in the long pulse mode (1.5

milliseconds) has been found to be effective. In one example, twenty subjects were treated with a single pulse using 15-20 joules/cm² in a 7.0 millimetre elliptical spotsize. A total of 120 treatment sites were assessed. A 60% rate of clearing was obtained after two treatments and the incidence of post-treatment hyperpigmentation was 75%.

To decrease the risk of post-treatment hyperpigmentation, the multiple pulse technique of the present invention may be used. In one example, a multiple pulse energy of 8-12 joules/cm² with a pulse width of 1.5 milliseconds was applied to the target area. The pulses were repeated 3-5 times at a repetition rate of 5-10 Hz. A 300 micron vessel has a thermal relaxation rate of approximately 100 milliseconds or 0.1 of a second. Since a vessel heated by one pulse loses 50% of its heat in approximately 0.1 seconds, a repetition rate of 10 Hz produces more efficient cumulative heating than a rate of 5 Hz. Present technology requires extensive modifications to achieve these higher repetition rates. Because of this limited availability to provide the preferred repetition rate of 5-10 Hz, the applicability of the present invention to small calibre vessels is limited.

For treating vessels with a diameter of 0.5-2.0 millimetres, lower repetition rates may be used. A vessel with a diameter of 0.5 millimetre has a thermal relaxation time of approximately 250 milliseconds or longer. Therefore, a laser with a repetition rate of 1-4 Hz can produce cumulative heating and higher repetition rates would produce greater efficiency. At larger diameters, the thermal relaxation time increases. A vessel with a diameter of 1.0 millimetre may have a thermal relaxation time approaching one second and at 2.0 millimetres the thermal relaxation time may approach four seconds. Therefore, with increasing vessel diameter, lower repetition rates become more effective. For a vessel of 1 millimetre, a repetition rate of even 0.5 Hz will be able to produce cumulative heating.

For vessels within the superficial dermis, wavelengths as low as 585 nm will achieve sufficient penetration. For oxyhemoglobin, the 585 nm wavelength produces the best absorption although longer wavelengths can be useful. For venous telangiectasia, where oxygen tensions are lower, deoxyhemoglobin is an efficient target chromophore for longer wavelengths between 600-1000 nm. Therefore, to treat telangiectasia of this size and depth, a variety of laser systems producing a range of wavelengths may be useful. These systems include a flashlamp pulsed dye laser (585-595 nm x 1.5 milliseconds), a long pulse Ruby laser (690 nm x 3 milliseconds) or an Alexandrite laser (700-1000 nm x 1-3 milliseconds). All of these systems may be equally useful although for venous type telangiectasia the longer wavelengths are preferable. All of these systems are used in the present invention in conjunction with some method of epidermal cooling, such as chilled Vigilon, or proprietary systems as are available with the long pulse Ruby laser.

TABLE 5

vessel size	0.5 mm. - 2 mm.
wavelength (nm)	585 - 595
pulse duration (milliseconds)	1.5
number of pulses	5 - 10
energy (joules/cm^2)	10 - 20
repetition rate (Hz)	0.5 - 1

The present invention was applied to these larger vessels using a wavelength of 585-595 nm with a pulse duration of 1.5 milliseconds. The energy used was 10-20 joules/cm^2 at a repetition rate of 0.5 - 1 Hz. The number of pulses was 5-10. The precise energy level and the number of pulses will be determined by a skilled clinician based on factors commonly used in conventional treatments to determine such parameters.

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These factors include the patient's skin type and target vessel size and type. Generally, for type II and type III skin, lower energy levels give a greater margin of safety since epidermal absorption by melanin is a greater problem with these skin types. For venous type telangiectasia, a longer wavelength is favoured and would be the preferred option for a vessel at the deeper levels of the upper dermis. With an increased wavelength, slightly increased energy levels are generally required to compensate for a slightly lower absorption rate.

TABLE 6	
wavelength (nm)	690
pulse duration (milliseconds)	1 - 3
number of pulses	5 - 10
energy (joules/cm²)	10 - 20
repetition rate (Hz)	0.5 - 1

A further trial used a wavelength of 690 nm, a pulse duration of 1-3 milliseconds, energy of 10-20 joules/cm², a repetition rate of 0.5-1 Hz, and 5-10 pulses. This longer wavelength may be more useful for venous type telangiectasia and deeper, thicker or larger calibre vessels. Again, the clinician will select specific energy levels and repetition rates depending upon skin type and vessel size. A larger vessel can be heated with lower repetition rates although there is an optimal rate for each vessel size. The number of pulses required will increase with an increase in vessel diameter. However, increasing the number of pulses can also be used to compensate for lower energy levels used in skin types II and III.

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TABLE 7	
wavelength (nm)	750
pulse duration (milliseconds)	1.2
number of pulses	5 - 10
energy (joules/cm²)	10 - 12
repetition rate (Hz)	1 - 2

A further trial used a longer wavelength of 750 nm, with a pulse duration of 1-2 milliseconds. The energy used was 10-12 joules/cm², with a 2 millimetre spotsize. The repetition rate was 1-2 Hz with 5-10 pulses. The longer wavelength of the Alexandrite laser used in this trial is more useful for venous telangiectasia and larger, thicker vessels.

The energy required to achieve coagulation temperature (an increase in temperature of approximately 50°C) can be delivered in any combination of energy and number of pulses. The exact combination will vary with skin type, vessel size, type of telangiectasia, and other characteristics. At 750 nm, a vessel of 0.5 millimetre diameter at 0.5 millimetre depth requires about 30 joules/cm² to achieve the required temperature change. This energy can not be delivered in one pulse since epidermal heating and thermal shock would be excessive. As well, present technology cannot deliver the required peak power to emit this amount of energy in one pulse. With the present invention, using the principle of cumulative heating at a repetition rate appropriate for a given vessel diameter allows for the energy required to be delivered in multiple pulses until visible coagulation is achieved. For the 0.5 millimetre vessel, the combination of treatment parameters may be 10 joules/cm² x 2.0 millimetres spotsize x pulse duration of 1 millisecond x repetition rate 2 Hz x 10 pulses. For a larger vessel of 1 millimetre, the combination of treatment parameters may be 10 joules/cm² x 2.0 millimetres spotsize x pulse duration of 2 milliseconds x

repetition rate 1 Hz x 5 pulses. The shorter pulse duration in the first set of treatment parameters allows for a higher repetition rate. The lower repetition rate in the second set of treatment parameters achieves efficient heating since the thermal relaxation time of a 1.0 millimetre vessel approaches 1 second. Therefore, at a repetition rate of 1 Hz, the radiated vessel has lost only 50% of its heat when the second pulse is delivered. A lower number of pulses is required for the larger vessel since the relationship of vessel diameter to attained repetition rate is more optimal. For the smaller vessel of approximately 0.5 millimetre, the thermal relaxation time is of the order of 0.25 seconds. With the repetition rate of 2 Hz which is within the capability of available technology, the vessel has lost more than 50% of its heat by the time the next pulse arrives and the heating is less efficient. Application of the present invention at a repetition rate of 4 Hz would be more ideal but it is not yet attainable with present technology.

The above-described embodiments of the present invention are meant to be illustrative of preferred embodiments of the present invention and are not intended to limit the scope of the present invention. Various modifications, which would be readily apparent to one skilled in the art, are intended to be within the scope of the present invention. The only limitations to the scope of the present invention are set out in the following appended claims.

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THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method of using a laser to coagulate vessels comprising the steps of applying multiple pulses of a laser to a target vessel area, appropriate energy and pulse duration and in which the pulse repetition rate is approximately equal to or less than the inverse of the thermal relaxation time of the target vessel to cause cumulative heating resulting in coagulation of the vessel without excessive heating of the surrounding tissue.

2. A method of using a laser to coagulate vessels comprising the steps of:

selecting a target vessel area to be treated;

calculating the required energy rate of the laser according to factors such as the target vessel size, vessel depth, and vessel and skin type within the target vessel area;

selecting an appropriate wavelength and pulse duration of the laser which gives the required energy to increase the temperature of the vessel within the target vessel area for coagulation while maintaining the optimal skin to vessel ratios;

selecting the repetition rate according to the vessel diameter and the thermal relaxation time to achieve cumulative heating;

generating multiple pulses of laser light having said energy rate, wavelength, pulse duration, and repetition rate; and

exposing the target vessel area to multiple pulses of laser light.

3. The method according to claim 2 wherein said pulse duration is less than the thermal relaxation time of the target vessel.

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4. The method according to claim 3 wherein said repetition rate of the laser pulse measured in Hertz is approximately equal to 1/TRT wherein the TRT is the thermal relaxation time of the target vessel.

5. The method according to claim 4 wherein the wavelength is approximately between 580 and 1000 nm.

6. The method according to claim 5 wherein the wavelength is approximately between 620 to 920 nm where the target vessel is venous in nature.

7. The method according to claim 5 wherein the wavelength of the selected laser beam is approximately between 590 to 615 nm where the target vessel is a capillary or arterial in nature.

8. The method according to claim 5 wherein the vessel diameter is greater than 300 microns.

9. The method according to claim 8 wherein the treatment is applied to telangiectasia.

10. The method according to claim 9 wherein the treatment is applied to leg telangiectasia.

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ABSTRACT

The present invention is a method of using a laser to coagulate blood vessels and, in particular, using wavelengths between 580-1000 nm delivered in a multiple pulse technique. The fluence required for photocoagulation and irreversible vessel injury is delivered in a sequence of pulses which allows for cumulative heating of the irradiated vessel. Each pulse utilizes a subthreshold fluence delivered at a calculated repetition rate based on the thermal relaxation time of the targeted vessels to allow for efficient heating. Using several pulses at a lower fluence than would be required if the energy were delivered in one pulse avoids the thermal shock wave which results in vessel rupture and unwanted hyperpigmentation. Lower fluences also reduce the risk of epidermal injury and unwanted scarring. This method is particularly useful in the treatment of leg telangiectasia.